An Introduction to Atomic Layer Deposition with Thermal Applications

Dr. Vivek H. Dwivedi
NASA GSFC Code 545

What is a Thin Film?

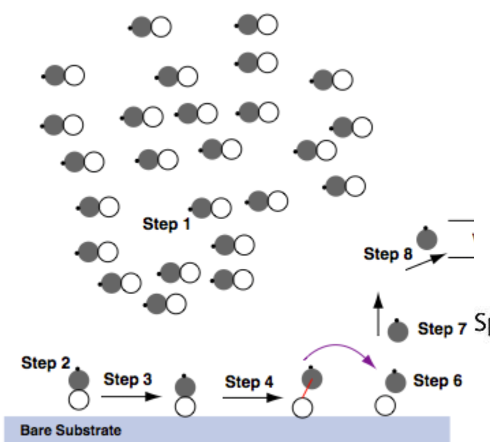
Thin film: thickness typically <1000nm.

Special properties of thin films: different from bulk materials, it may be –

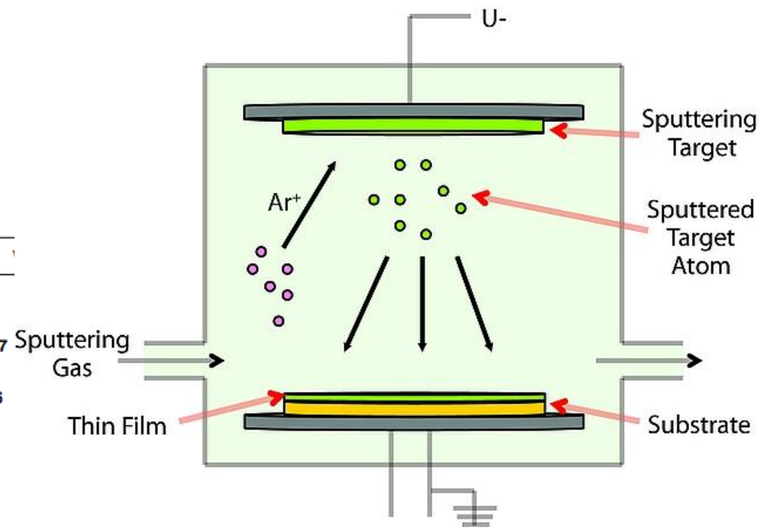
- Not fully dense
- Under stress
- Different defect structures from bulk
- Quasi - two dimensional (very thin films)
- Strongly influenced by surface and interface effects

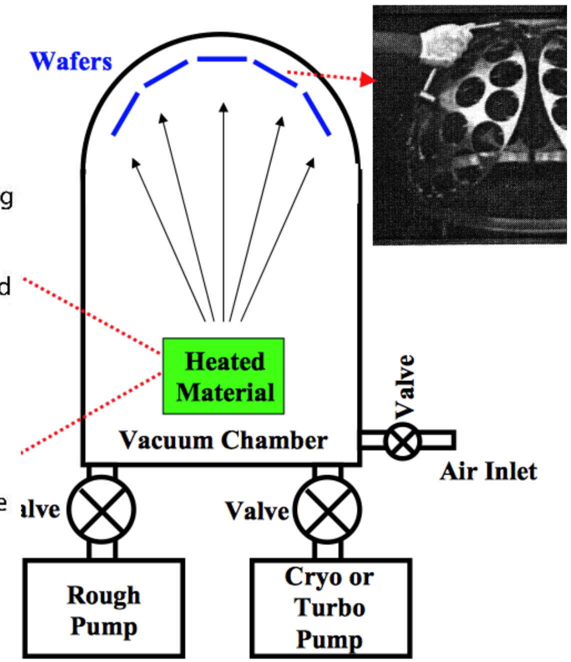
Other Deposition Techniques

CVD Process



1. Precursor gas phase reaction
2. Diffusion
3. Adsorption
4. Surface Process
5. Desorption
6. Diffusion
7. Purge

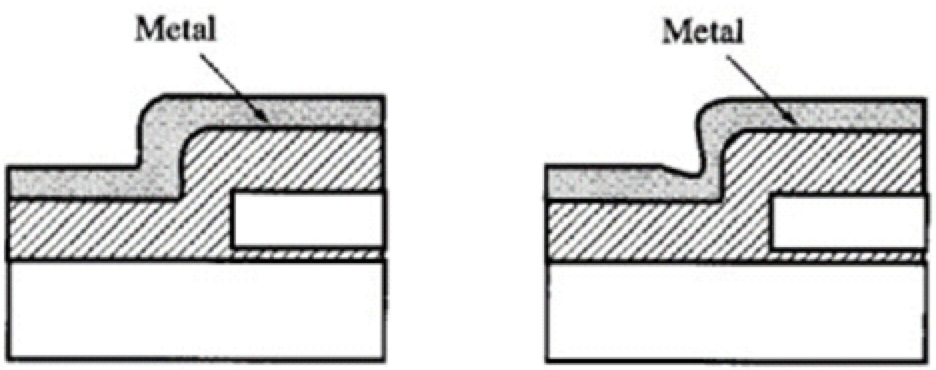




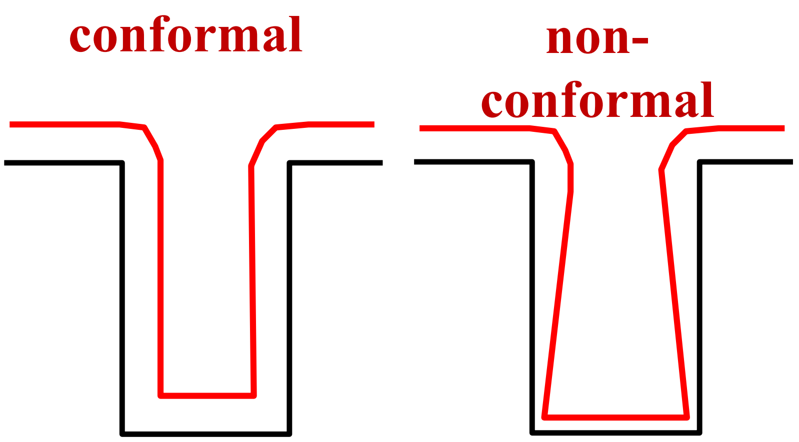
Common Denominator

- Deposition only occurs on substrates that "see" the target.
- Plasma process can damage the substrate
- Poor thickness control
- Poor Step Control
- High Pressure High Temperature Environment

Step Coverage Example



(a) (b)



Step coverage of metal over non-planar topography.

(a) Conformal step coverage, with constant thickness on horizontal and vertical surfaces.

(b) Poor step coverage, here thinner for vertical surfaces.

Introduction

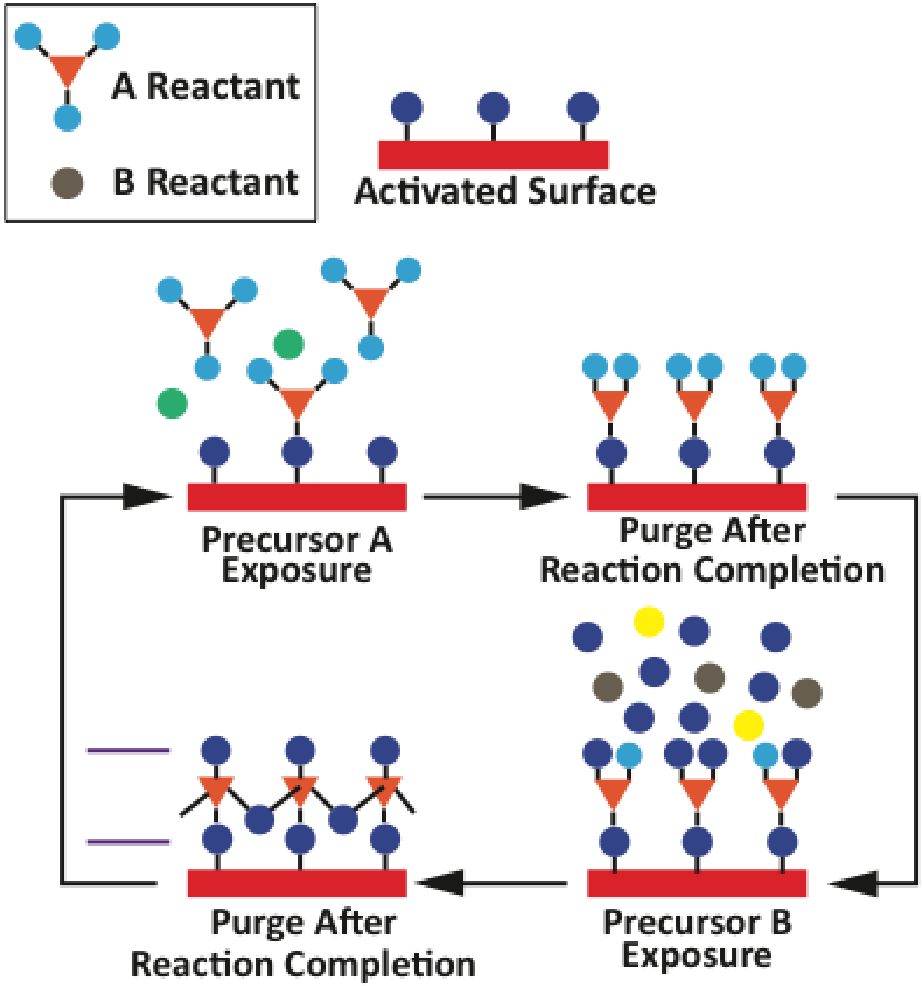
Atomic
Layer
Deposition

A thin film"nanomanufacturing" tool that allows for the conformal coating materials on a myriad of surfaces with precise atomic thickness control.

Based on:

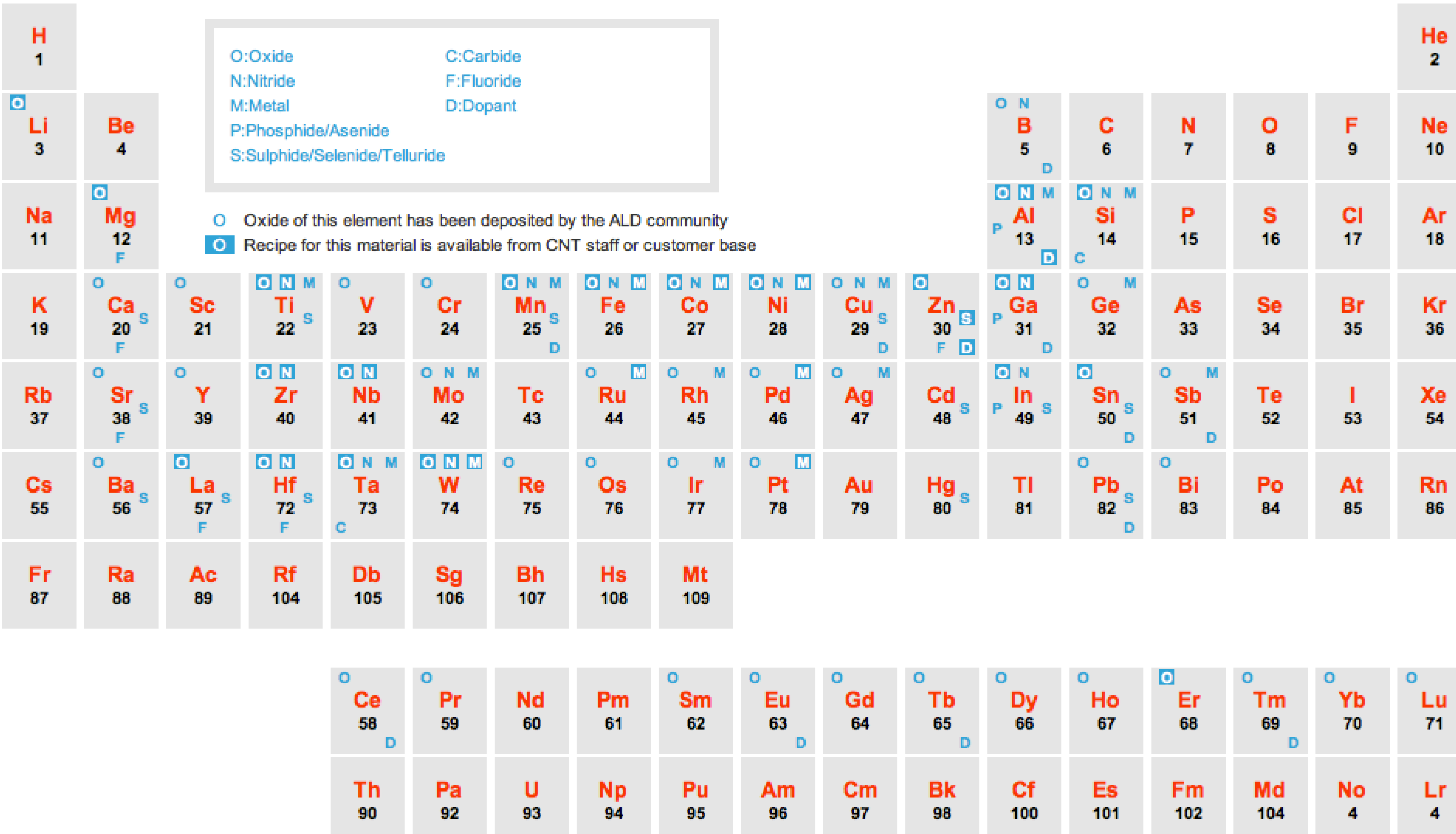
- **Paired gas surface reaction chemistries**
- **Benign non-destructive temperature and pressure environment**
  - **Room temperature -> 250 °C (even lower around 45 °C)**
  - **Vacuum**

ALD Procedure



- **A or B exposure = Half Cycle**
- **A+B = Full Cycle = 1 Monolayer**
- **Digital Process: ABABABAB**
- **Not Line of Sight, EVERYTHING GETS COATED**
- **Substrate Independent**

Periodic Table of ALD Films



Acknowledgements

- **Gordon, Roy (2008). Atomic Layer Deposition (ALD): An Enable for Nanoscience and Nanotechnology. PowerPoint lecture presented at Harvard University, Cambridge, MA.**
- **Elam, Jeffrey (2007). ALD Thin Film Materials. Argonne National Laboratory**

Advantageous Property

Precise Thickness Control

Thickness = $\mathscr{F}$(# monolayers)

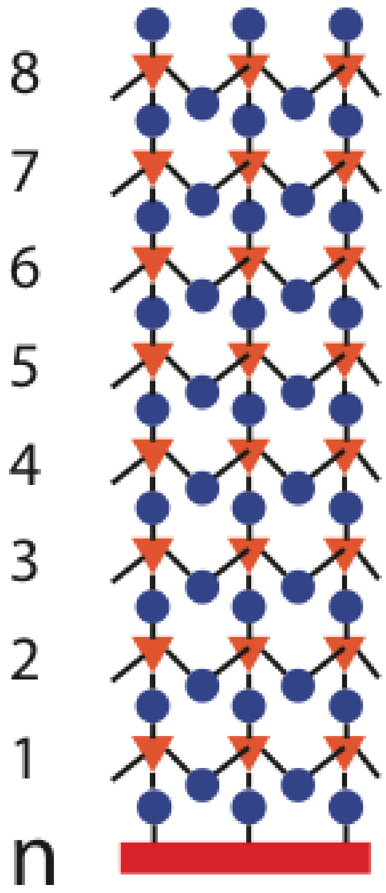
Example:

If 1 monolayer = 1 A

monolayers = 7

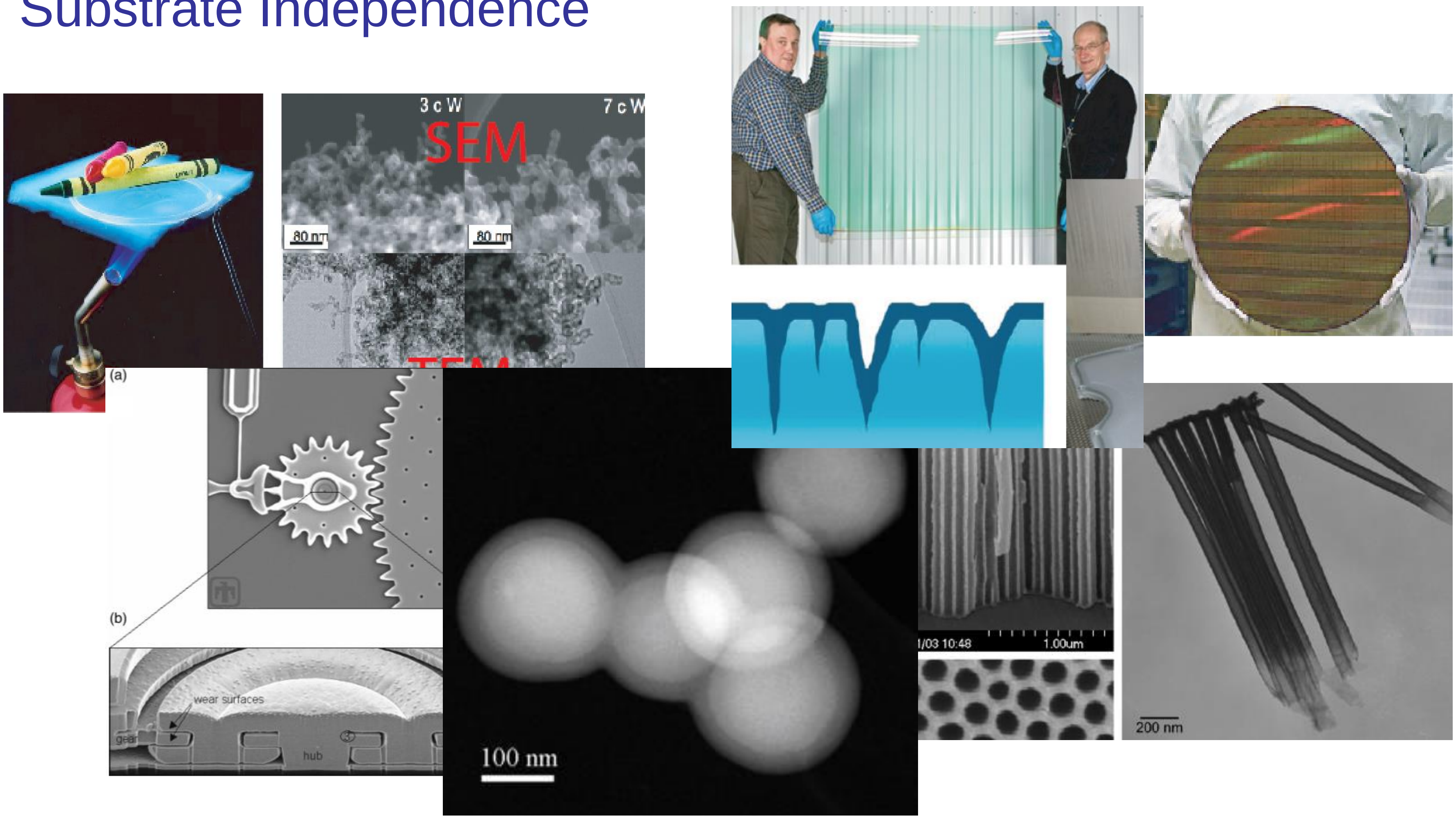
Thickness = 7 A

Reproducibility



Advantageous Property

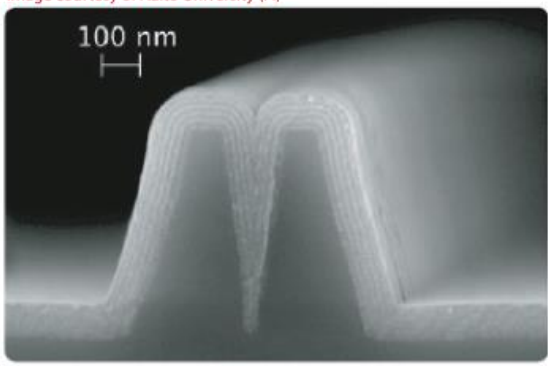
Substrate Independence

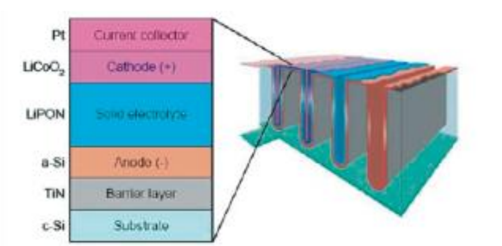


Advantageous Property

Epitaxial Growth

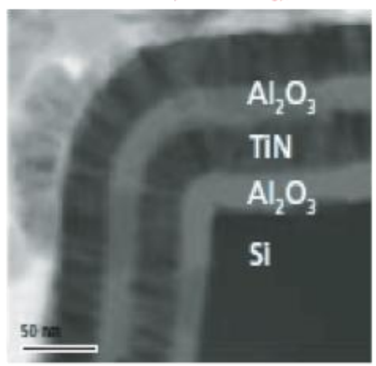
Artificial trench filled with an ALD nanolaminate
Image courtesy of Aalto University (FI)





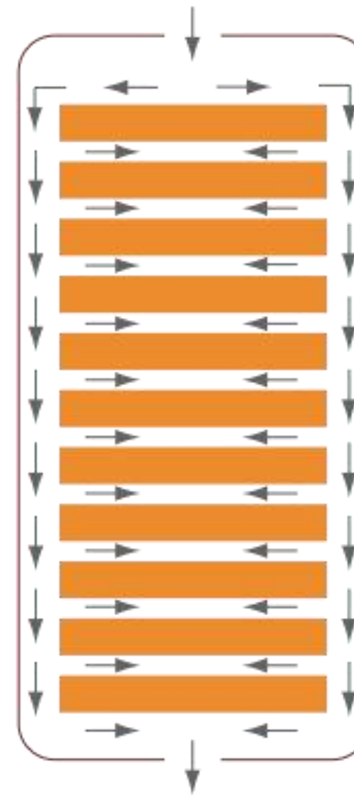
Schematic of a 3D battery integrated in a Si- substrate.
The cross-section shows the various functional layers in the battery stack as well as the candidate materials.
Knoops, H.C.M. et al., ECS Trans., 25 (2009) pp. 333-344

Multilayer consisting of:
Al2O3 - 25 nm
TiN - 20 nm
Al2O3 - 25 nm
Dr. Fred Roozeboom, NXP Semiconductors Research and Dr. Erwin Kessels, University of Technology, Eindhovend



Batch Process

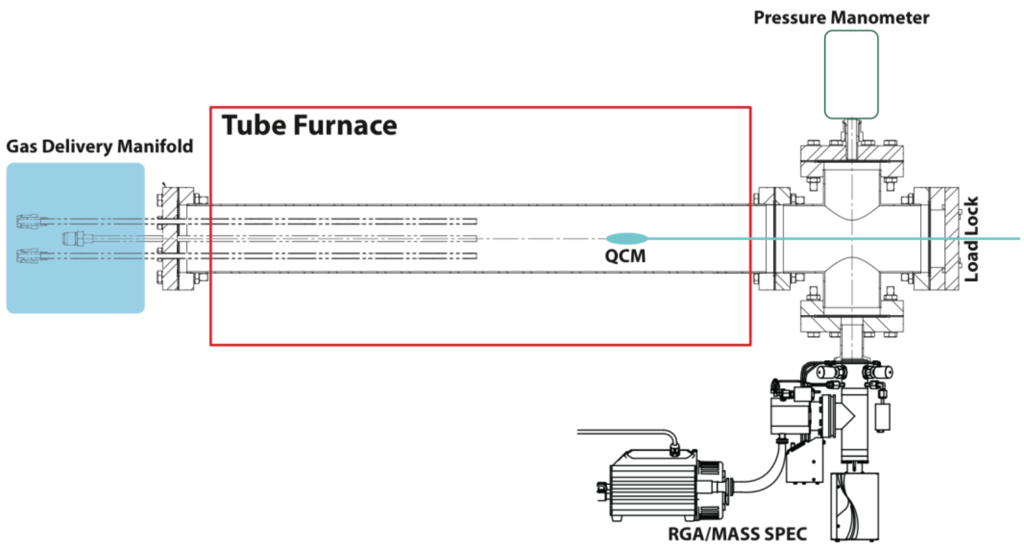
Coating Silver with Aluminum Oxide
http://www.glassonweb.com/

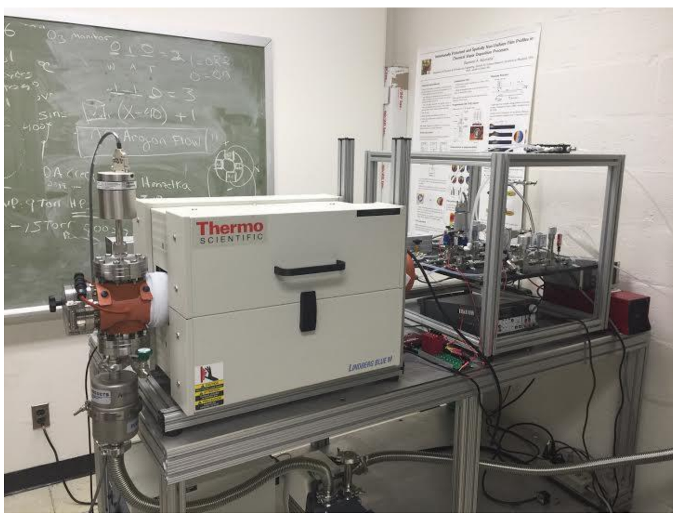


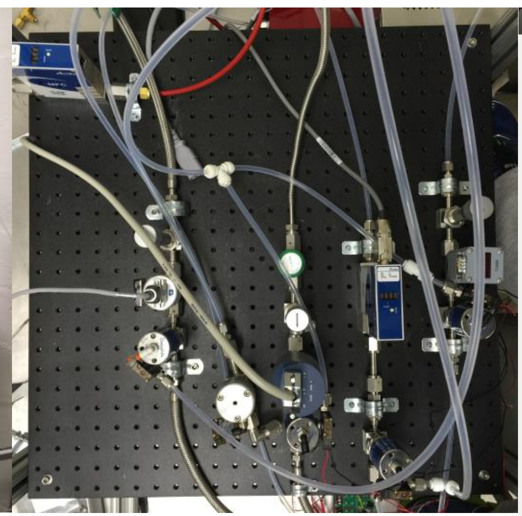
Building off a Commercial Reactor

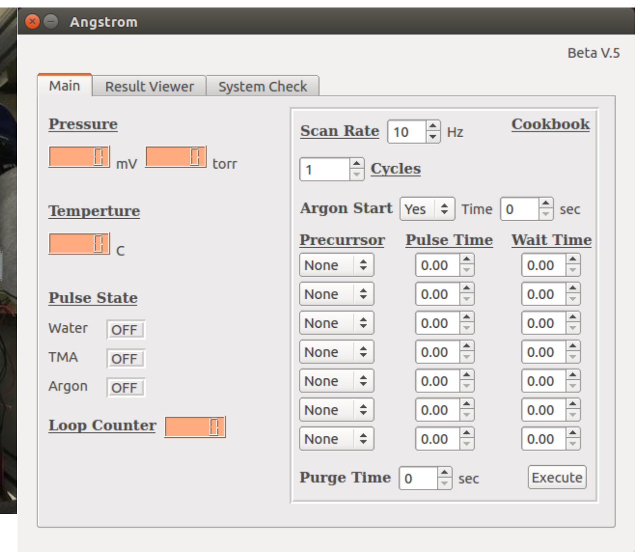
Commercial Options

In-House Experimental ALD System

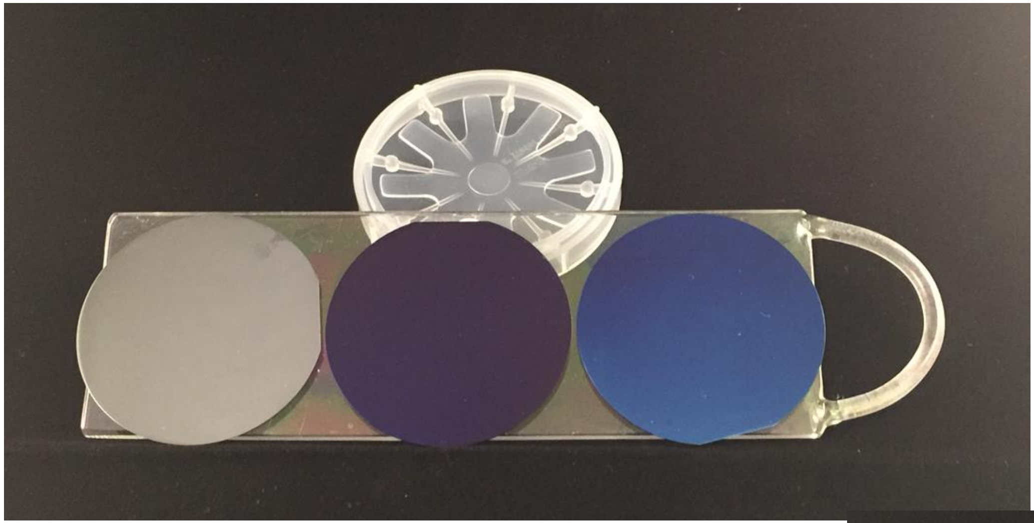


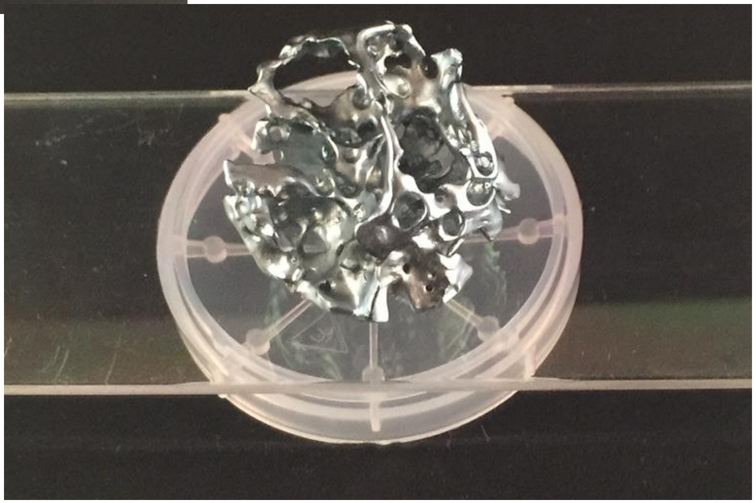




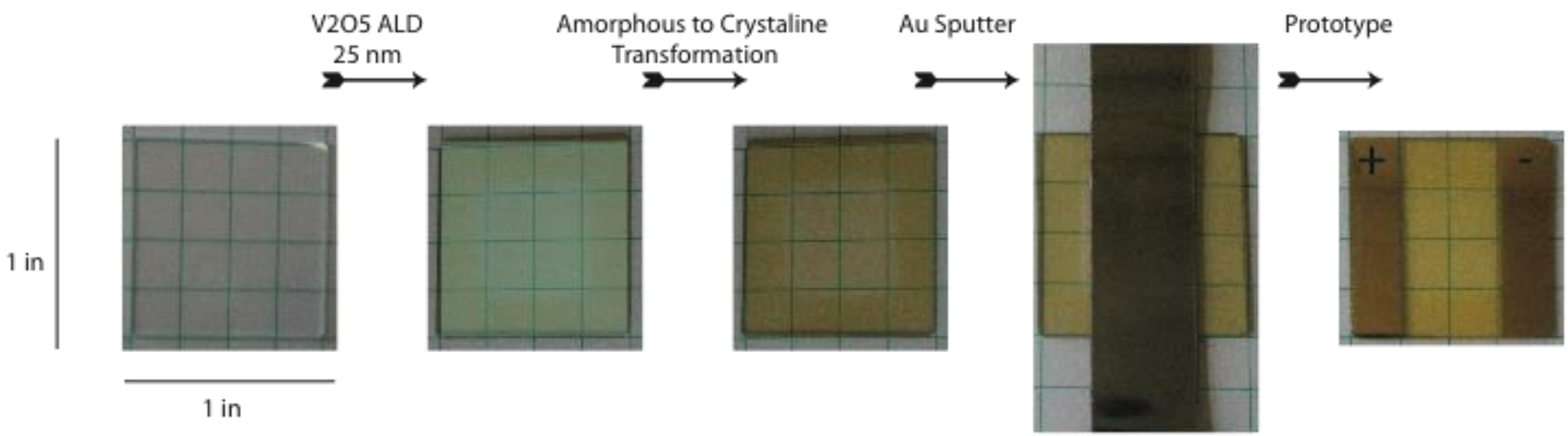


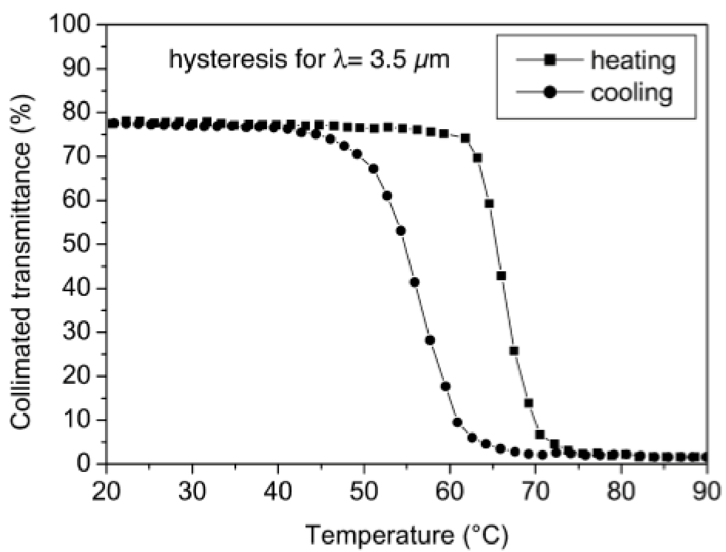
Thermal Applications and Results

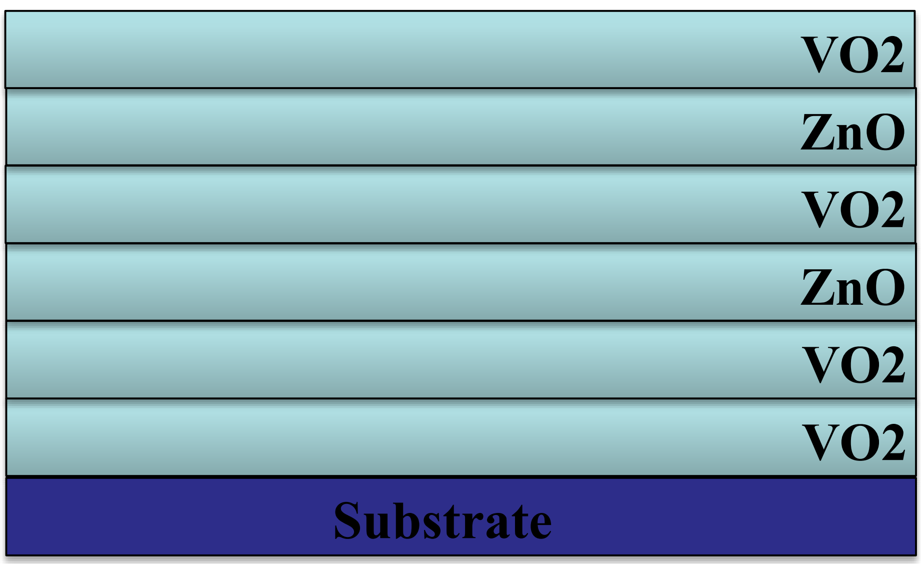




Passive Thermal Films

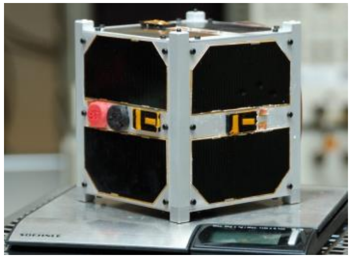


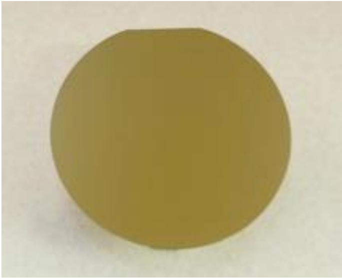


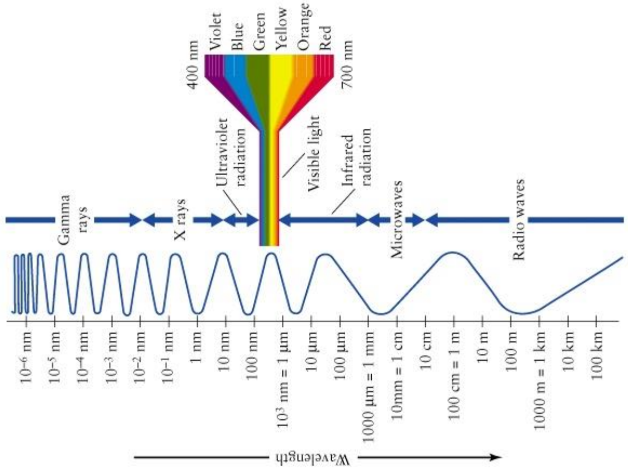


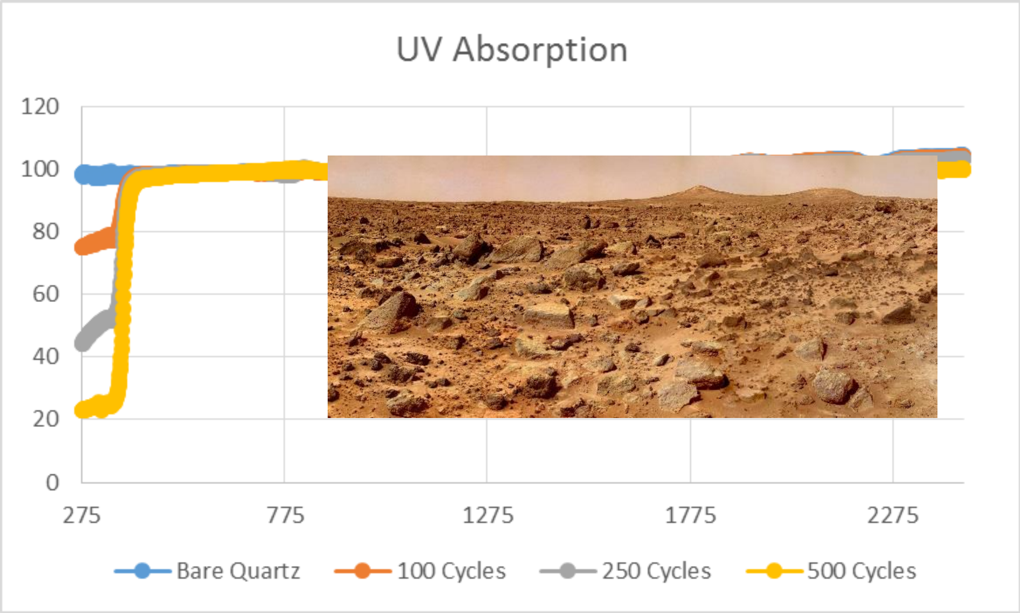
ZnO

$E = {}^{hc}/_{\lambda}$ where:
f = frequency in Hertz (Hz = ${}^{1}/_{sec}$)
λ = wavelength in meters (m)
c = the speed of light (299792458 ${}^{m}/_{s}$)
E = energy in electron Volts (eV)
h = Plank's constant (6.626068×10^{-34} ${}^{m2kg}/_{s}$)
E_{ZnO}=3.3 eV
λ_{ZnO} ~ 375 nm



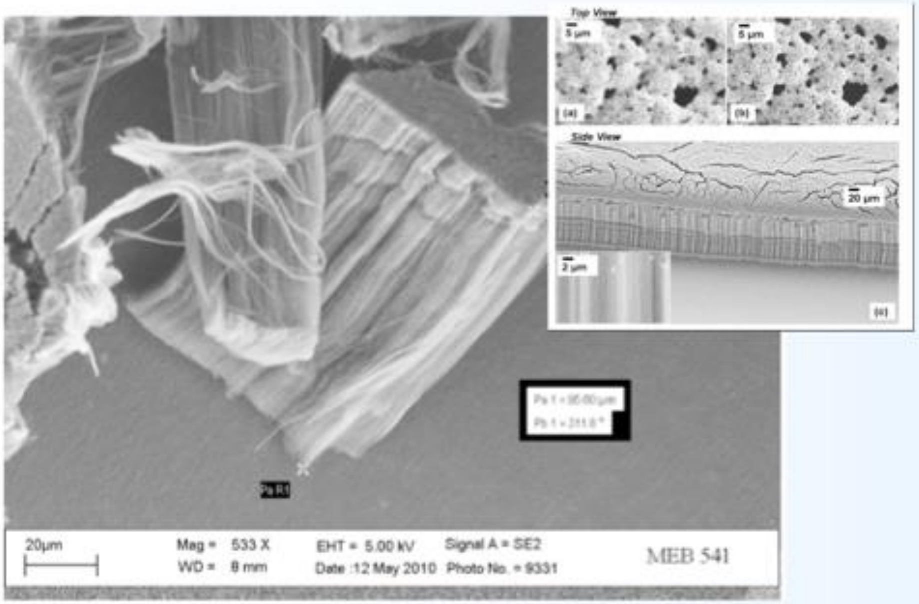


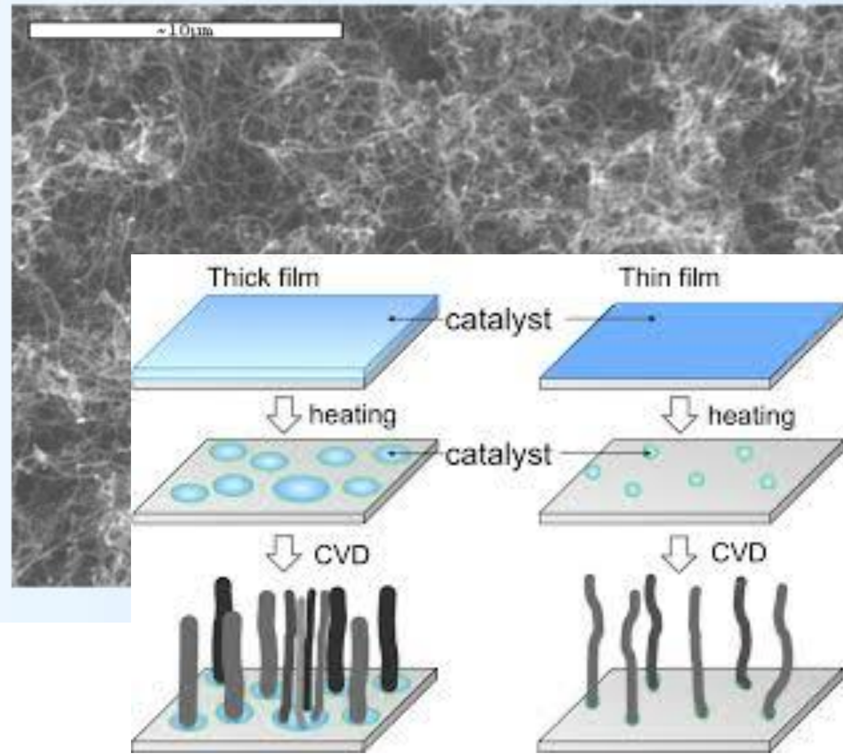




Blacker Than Black Carbon Nanotubes

Fe ALD on Complex Geometries for Carbon Nanotube Growth





Substrate + Catalyst + Gas = CNNT
Si,Ti, flat, 3d + Iron + Ethylene

Blacker than NASA Z306 Paint 10X Darker

Atomic Oxygen Protection

100 nm on Kapton
1000 Cycles
155 °C
Al_2O_3

GPM Funded an experiment at Glenn to determine AO effects on materials.

99% mass retention after a simulated 5 year flux

Questions?